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resistance; and 3) obtaining a durable rectifier. The resistance of the selenium layer can be decreased by the following methods: 1) reducing the thickness of the selenium layer; 2) removing metallic impurities from the selenium to increase its electroconductivity; 3) adding halogen admixtures to the selenium to increase its electroconductivity; and 4) heat-treating the selenium layer to increase its electroconductivity. The high resistance of the boundary layer between selenium and the contact electrode was practically eliminated by nickel-plating the steel or aluminum disks for the contact electrodes. The resistance of the boundary layer between selenium and the cathode was made a minimum only in the inactive part where practically no space charge exists for inverse currents. The resistance of the active part of the selenium boundary layer (the blocking layer) is made an optimum to obtain, on the one hand, a small direct resistance and, on the other, a high blocking resistance. The resistance of the selenium boundary layer is made an optimum by the following methods: 1) selection of the material for the cathode (use of cadmium alloys); 2) heat treatment to remove halogens from the surface of the selenium layer; and 3) deposition of various substances on the selenium surface (treating the selenium surface in sulfur vapors).

Selenium is the basic material for the production of rectifiers. The technology of factory purification of selenium for rectifiers was perfected in the USSR by B. Levi (NIUIF, Scientific Research Institute of Fertilizers and Insecto-fungicides). Important refinements in the technology were devised later by S. Golyand (NIOGAZ). The author, together with K. Astakhov, B. Levi, and N. Penin, studied the influence of impurities in selenium upon the properties of selenium rectifiers.

The influence of about 20 different elements was studied. It was established that the majority of impurities in quantities of 0.1 percent or more act unfavorably upon the rectifier's characteristics, namely, increasing the direct resistance, decreasing the block resistance and intensifying aging. The harmful impurities include: zinc, cadmium, mercury, tin, lead, arsenic, nickel, iron, sulfur, tellurium, and oxygen. Copper, silver, and antimony impurities were especially harmful, increasing the direct resistance and intensifying aging even in quantities of 0.001 percent. The beneficial effect of extremely small quantities of chlorine, bromine, and iodine (thousandths of a percent) in reducing the direct resistance was also established. At the same time, it was determined that too large a halogen content not only decreases the blocking resistance, but also lowers the breakdown voltage.

The selenium used in the USSR for rectifiers contains thousandths of a percent of chlorine and has no copper, silver, or antimony in it; the total of other metallic impurities does not exceed 0.01 percent (nonvolatile residue).

The contact electrode of a selenium rectifier is produced from sheets of steel or aluminum from 0.8 to 1.5 millimeters thick. These sheets are cut and stamped so that the surface of the disk is perfectly flat in order that a thin uniform selenium layer may be deposited.

The sandblasting which follows guarantees good mechanical contact and the proper electrical contact of the selenium with the metallic electrode. The disks are then nickel-plated (1 or 2 microns thick), which ensures low direct resistance of the newly produced rectifiers and affords protection against aging. The technological process for thin nickel-plating of steel and aluminum disks for contact electrodes was developed by the author together with A. Gopius.

Fusion is used to deposit the selenium on the contact electrode: the contact electrode is heated to approximately 250 degrees centigrade and the selenium is fused on; the rapidly cooled disks with the fused vitreous selenium are then pressed to obtain a thin uniform selenium layer. The disks are pressed while the selenium is heated to 110-120 degrees centigrade at a pressure of several tens of kilograms per square centimeter. The selenium is held under pressure until the surface section of the layer crystallizes. The selenium is 0.07 to 0.1 millimeters thick after pressing. Special presses, which ensure constant uniform pressure, are used in this process. The selenium is protected from contamination by special chrome-plated matrices.

The selenium layer is heat-treated in furnaces at a temperature of around 215 degrees centigrade. The selenium surface is left uncovered during this process. Chlorine is partially volatilized from the upper part of the selenium

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layer, thus increasing the blocking resistance of the rectifier. The electroconductivity of selenium in the layer is considerably increased because of the increase in the number of defects of the crystal-lattice in connection with the fact that the temperature during heat-treating is close to the temperature of fusion (217 degrees centigrade) for selenium. Using X-ray analysis, G. Zhdanov and Ya. Sharvin showed that the parameters of the selenium lattice do not change any more in heat-treatment than in aging of the rectifiers. Special furnaces with accurate automatic temperature regulation are used for heat-treatment.

Sulfur is deposited on the selenium surface after heat-treatment. The disks are held in sulfur vapors at a temperature of about 150 degrees centigrade for several tens of minutes. The sulfur dissolves into the surface of the selenium layer and thus increases its resistance.

A metal spray gun using compressed air, which shoots the fused metal on the selenium, is used for covering the rectifier disks with the cathode. Alloys of technically pure metals, cadmium, tin, and bismuth, are used for metal-plating. The author's research, conducted jointly with A. Shpagin and N. Penin, showed that the cathode material strongly influences the direct and blocking resistances of the rectifier, as well as aging and electroforming. Changing the cadmium content from 10 to 100 percent (tin and bismuth the rest) has practically no influence upon the rectifier's characteristics. The use of metals (magnesium, calcium) chemically active with respect to selenium causes exceedingly high direct resistance and rapid aging of the rectifiers. Selenium rectifiers with zinc cathodes are very close in their characteristics to rectifiers with cadmium cathodes.

Rectifiers with thallium cathodes have the greatest increase in blocking resistance during electroforming. These rectifiers also have the highest ratio of blocking to direct voltage and thus are most efficient. However, rectifiers with thallium cathodes or with cathodes having slight thallium impurity age more rapidly than the usual rectifiers.

Electroforming at the plants producing selenium rectifiers is carried out after metal plating by passing a high inverse current through the rectifiers (current density of several tens of milliamperes per square centimeter) for a length of time from several tens of minutes to several hours. The rectifier's rating as to blocking voltage is increased 1.5 to 2 times in this process. Special panels which automatically maintain the current within the necessary limits are used for electroforming. In order to limit the direct current and avoid excess heating, the rectifiers are placed in opposition and connected to the alternating-current circuit through an effective resistance. The great influence of the cathode material, magnitude, current, and temperature in the electroforming process indicates the important role of the ions of the cathode metal in this process. Under the action of the strong electric field, they penetrate into the barrier layer and change its electroconductivity.

After molding, the rectifiers are tested. All newly produced rectifiers are tested for electrical strength and rated with respect to direct and blocking voltages. In the USSR, selenium rectifiers are rated on direct current with a direct-current density of 50 milliamperes per square centimeter (or 40 microamperes per square centimeter) and inverse current density of 4 milliamperes per square centimeter (or 2 microamperes per square centimeter). A test voltage of 50 volts is used.

In a brief discussion of the vacuum method of producing selenium rectifiers, it is stated that work is being done on this method in the USSR, but that the equipment outlay required for the method is enormous and that further improvement of the method is necessary.

The NIKFI has proposed a new set of selenium rectifiers of diameters of 5, 10, 20, 30, 50, 80, and 130 millimeters. This set is distinguished by the small number of different sizes. Moreover, parallel connection of two rectifiers will not replace a rectifier of larger diameter.

Selenium rectifiers are widely used for the following purposes:

1. Charging Batteries -- Selenium rectifiers are used in garages, and airports to charge starter batteries for automobiles, aircraft, and other machines

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using internal-combustion engines.

2. Supplying Electrolysis Baths -- Galvanic selenium rectifiers are rated for currents from tens to thousands of amperes at voltages of the order of 10 volts. Selenium rectifiers have been developed for currents up to 1,000 amperes in the USSR. Westinghouse of England developed 15,000-ampere rectifiers in 1945. The current is regulated in many designs by changing the number of turns or the transformer winding. Rectifiers immersed in oil may be operated for prolonged periods when installed directly near the bath. Selenium rectifiers are used in electrolysis shops for plating copper, zinc, cadmium, chrome, nickel, etc. Selenium rectifiers have been designed in the NIKFI to supply baths for silver regeneration in cine-copying processes.

3. Supply for Electric Arcs -- Several types of selenium rectifiers have been designed in the USSR to supply electric arcs with currents from 3 to 50 amperes at voltages from 20 to 60 volts. A selenium rectifier was designed with economical ferroresonance stabilization of the current for an arc projector of 2-2.5 kilowatts' power. A regulated selenium rectifier has also been designed to supply the electric arc used in spectral analysis.

4. Excitation of Electric Generators -- S. Yuditskiy devised a system of excitation and compounding of synchronous generators by means of selenium rectifiers without using rotating exciters.

5. Supply of Radar Installations and Radio Communication Equipment -- Despite the low efficiency of selenium rectifiers, they are often used instead of ionic devices because of their prolonged and continuous operation and high mechanical strength.

6. Measuring Instruments -- Special measuring selenium rectifiers have been designed (NIKFI) with increased stability of resistance and decreased capacitance for operation at 10 kilocycles.

7. Supplying Electromagnets of Various Units -- Selenium rectifiers are used to supply the electromagnetic plates of grinding machines. They are also used to supply driving electromagnets, for example, oil switches.

A low-power direct-current generator has been designed with permanent magnets and selenium rectifiers in the main circuit. Despite a certain loss of efficiency, the new system is more reliable and does not require much maintenance.

8. Current and Voltage Stabilizers and Regulators -- The author designed an economical static voltage regulator using selenium rectifiers and magnetically saturated coils.

9. Magnetic Amplifiers -- Selenium rectifiers have recently been used in magnetic amplifiers of various automatic regulation equipment.

10. Grid Control of Ionic Rectifiers -- Selenium rectifiers are used to obtain the negative bias voltage on the grids of thyatrons or controlled mercury rectifiers. I.L. Kaganov designed static magnetically saturated regulators for grid control of power rectifier and inverter units.

Selenium rectifiers are also used for signaling and automatic blocking on railroads, supplying telephone and telegraph communication lines and series connection of rectifiers in the line to double their carrying capacity, supplying equipment used in testing cable insulation, supplying X-ray equipment, detection in high-frequency circuits, electrostatic gas purification, cathodic corrosion protection, telecontrol, arc quenching in direct-current circuits etc.

In conclusion, it is specified that the production of selenium rectifiers must be expanded, and that new types must be developed.

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